(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
25 January 2001 (25.01.2001)

PCT

(10) International Publication Number
WO 01/06473 A2

(51) International Patent Classification[7]: G08B 13/00

(21) International Application Number: PCT/IL00/00421

(22) International Filing Date: 18 July 2000 (18.07.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
130985 19 July 1999 (19.07.1999) IL

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(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

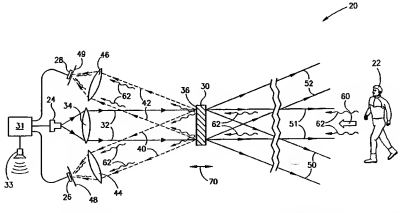
(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:

— *Without international search report and to be republished upon receipt of that report.*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: LASER MOTION DETECTORS



(57) Abstract: A motion detector for detecting motion of a body in a surveillance zone comprising: at least one laser that produces laser light; at least one photodetector that generates signals responsive to light incident thereon; a light distributor that receives laser light from a laser of the at least one laser and distributes a portion of the light into a plurality of sensor light beams that extend into the surveillance zone and a portion of the light into at least one reference light beam, which does not extend into the surveillance zone, said at least one reference beam being incident on a region of the at least one photodetector, wherein the distributor is positioned and configured so that light reflected from a sensor beam by an object in the surveillance zone is received by the distributor and directed onto said region of the at least one photodetector; and circuitry that receives signals generated by the at least one photodetector and processes the signals to determine if reflected light incident on the at least one detector is Doppler shifted as a result of motion of the body, and if so, generates a signal indicating motion of the body.

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LASER MOTION DETECTORS

FIELD OF THE INVENTION

The present invention relates to motion detectors using lasers and especially to application of such motion detectors in intruder detection systems.

BACKGROUND OF THE INVENTION

Intruder detection systems for detecting the presence and movement of an intruder in an area or volume of space, hereinafter referred to as a "surveillance zone", are well known in the art. Such systems are used for example to protect homes and businesses from unauthorized entry and in less sinister applications to detect an individual's presence in a room.

Various different types of intruder detection systems exist and they employ different technologies to detect an intruder. Common among these detection systems are different types of active and passive infrared (PIR) detection systems, systems that use microwaves for detection and systems that use acoustic waves. Less common are intruder detection systems using laser light.

All of the various detection systems have to contend with providing high efficiency for detecting an intruder while providing a low rate of false alarms (*i.e.* a low rate of "detecting" intruders that are not there). Generally as components in a detection system provide higher sensitivity for detecting changes in a surveillance zone caused by an intruder, the system has to provide more sophisticated and complicated stratagems to prevent false alarms and assure reliable system operation.

For example, PIR detection systems are particularly sensitive to changes in sensitivity of IR detectors caused by changes in ambient temperature and these systems are generally designed with means for adjusting system components responsive to these changes. The ability of an IR detection system to detect an intruder is also often affected by what the intruder wears and how the intruder moves in a surveillance zone protected by the system. Radio frequency (RF) detection systems, while not particularly sensitive to ambient temperature, have to contend with RF background noise from a plethora of devices and appliances that can interfere with reliable operation. Similarly, acoustic systems generally operate in noisy environments that can affect the reliability with which these systems operate. Often intruder detection systems use two different types of detection technologies in order to reduce false alarms and improve system reliability.

A PIR detection system is described in US Patent 5,629,676 to Kartoun, et al. The system comprises a temperature sensor and adjusts a detection threshold of components in the system responsive to changes in ambient temperature. A "dual" detection system is described in

US Patent 5,684,458 to Calvarese. A detection system described in this patent comprises both an RF Doppler detection subsystem and a PIR detection subsystem. An alarm is raised indicating an intruder only when the RF detection subsystem and the PIR subsystem simultaneously indicate the presence of an intruder.

A laser detection system described in US patent 5,910,767 to Frucht uses a laser beam to continuously scan a surveillance zone. Reflectivities with which objects and features in the surveillance zone reflect light from the laser beam and distances to the features and objects are measured using the laser beam and stored. During subsequent scans with the laser beam, distances to the objects and features and reflectivities with which they reflect laser light are compared to the stored distances and reflectivities and analyzed to determine whether or not an intruder is present in the surveillance zone. Scanning is accomplished by mechanically rotating a mirror that reflects the laser beam into the surveillance zone.

The use of Doppler shifting, and in particular Doppler shifting of light for detecting motion is well known in the art. US Patent 4,611,912 to Falk describes a method and apparatus for optically measuring velocity of an object and distance to the object. The velocity is determined by measuring the amount by which the velocity of the object Doppler-shifts light from a laser diode.

SUMMARY OF THE INVENTION

An aspect of some embodiments of the present invention relates to providing an improved intruder detection system that provides high detection efficiency and low false alarm rate and that is relatively inexpensive and simple to produce and maintain.

An aspect of some embodiments of the present invention relates to providing a detection system comprising a plurality of in-phase laser beams that simultaneously illuminate different portions of a surveillance zone. If movement is detected in one or more of the laser beams, a signal is generated indicating the intruder's presence.

According to an aspect of some embodiments of the present invention, Doppler shifts in the frequency of light reflected from a laser beam of the plurality of laser beams, by an intruder moving in the surveillance zone, are used to detect the intruder.

An intruder detection system, in accordance with an embodiment of the present invention comprises a laser and at least one photodetector sensitive to light radiated by the laser. Light from the laser is incident on a means for diffracting light, hereinafter referred to as a "diffractor", such as diffraction grating or suitable holographic diffraction plate. Preferably, most of the laser light that is incident on the diffractor is forward-diffracted into a plurality of laser beams, hereinafter referred to as "sensor beams". The sensor beams spread out from the

diffractor and extend into different regions of the volume of a surveillance zone protected by the intruder system. Preferably a small portion of the incident laser light is back-diffracted by the diffractor into one or more beams, and preferably a plurality of beams, hereinafter referred to as "reference beams". Each reference beam is detected by a photodetector of the at least one photodetector. In some embodiments of the present invention the at least one photodetector comprises a plurality of photodetectors and each reference beam is detected by a different one of the plurality of photodetectors.

If a sensor beam illuminates an intruder present and moving in the surveillance zone, light from the sensor beam is reflected back to the diffractor. Some of the reflected light is diffracted by the diffractor onto one or more of the photodetectors. Each of the photodetectors generates an output signal responsive to both reference beam light and light reflected from the sensor beam that is incident on the photo-sensor. However, the frequency of the reflected light is generally Doppler shifted by the movement of the intruder. As a result, the output signal from each photodetectors has a signal component, hereinafter referred to as a "Doppler signal" characterized by the Doppler shift frequency, which Doppler shift frequency is determined from the Doppler signal using methods known in the art. If a determined Doppler shift frequency has a value that lies within a range of values that are indicative of the motion of an intruder, and is characteristic of intruder motion, the detection system generates an output signal indicating an intruder's presence.

In some embodiments of the present invention, a particular value for a Doppler shift frequency is not determined or required in order for the intruder detection system to generate an output signal indicating an intruder's presence. An output signal is generated if an amount of energy in output signals from photodetectors is greater than a predetermined minimum threshold quantity of energy in a band of frequencies characteristic of Doppler shift frequencies caused by an intruder. Depending upon the purpose for which the intruder system is being used, the output signal indicating the intruder's presence may, for example, generate an alarm, turn on an appliance or open a door - or just wish the intruder a nice day.

According to an aspect of some embodiments of the present invention, light reflected by an intruder from a sensor beam illuminating the surveillance zone is used to determine both a magnitude and a direction of a component of motion of the intruder in the surveillance zone.

In some embodiments of the present invention, the diffractor is mechanically vibrated back and forth in a direction perpendicular to the plane of the diffractor. This Doppler shifts the frequency of the reference beams by an "offset Doppler-shift" that depends upon the velocity of the diffractor. When a photodetector receives light reflected from a sensor beam by a moving

intruder (or object) it generates a Doppler signal having a Doppler frequency that is the sum of the offset Doppler frequency and a Doppler shift frequency caused in the reflected light by the intruder's motion. If the Doppler frequency of the Doppler signal is less than the offset Doppler shift, the intruder is moving with a component of velocity in the direction of motion of the diffractor. If the Doppler frequency of the Doppler signal is greater than the offset Doppler shift, the intruder is moving with a component of velocity in a direction opposite to the direction of motion of the diffractor. The magnitude of the component of velocity is determined from the magnitude of the Doppler frequency of the Doppler signal and the known magnitude of the offset Doppler shift. As a result, a component, towards or away from the intruder detection system, of the motion of the intruder can be determined, in accordance with an embodiment of the present invention, from the Doppler frequency of the photodetector Doppler signal and the direction of motion of the diffractor.

In some embodiments of the present invention, the component of motion of the intruder is determined by introducing a time dependent phase shift into light reflected by an intruder. The time dependent phase shift appears as a frequency shift, an offset Doppler shift, in *intruder reflected light*. A Doppler frequency of a Doppler signal generated by a photodetector that receives the intruder reflected light is greater than or less than the offset Doppler shift generated by the phase shift depending upon the direction of motion of the intruder. For example, if the time dependent phase shift increases the frequency of intruder reflected light and the intruder is moving towards or away from the source of the sensor beams, the beat frequency will respectively increase or decrease. Methods for introducing time dependent phase shifts in light are known in the art. For example, a time dependent phase shift can be introduced into intruder reflected light by passing sensor beam light and intruder reflected light through a plate of piezoelectric material whose optical length is controlled by an electric field.

In some embodiments of the present invention, quadrature detection is used to determine the component of motion of an intruder. Reflected sensor light from an intruder passes through a linear polarizer and quarter wave plate so that it becomes circularly polarized. The circularly polarized reflected light is filtered through a first polarizer having its polarization axis along a first direction and focused on a first photodetector of the plurality of photodetectors. The circularly polarized reflected light is also filtered through a second polarizer having its polarization axis along a second direction and focused on a second photodetector of the plurality of photodetectors. The first and second polarization directions are optimally perpendicular to each other. As a result, reflected light reaching the first photodetector is 90^{o} out of phase with respect to that reaching the second photodetector. The

Doppler signals from the first and second photodetectors are therefore 90° out of phase with respect to each other and function as a pair of "Doppler quadrature signals". One of the quadrature signals leads the other. Which one leads depends upon whether the frequency of the reflected sensor beam light is Doppler shifted up or down, which of course depends upon the direction of motion of the intruder. Therefore, by determining which of the quadrature Doppler signals leads the other it is possible to determine whether the reflected sensor beam light is Doppler shifted up or down. The direction of motion of the intruder is towards or away from the source of the sensor beams if the frequency of the reflected sensor beam light is Doppler shifted respectively up or down.

According to an aspect of some embodiments of the present invention a vertical cavity surface-emitting laser (VCSEL) is used to provide light in an intruder detection system. These lasers are relatively inexpensive, efficient sources of laser light having coherence lengths suitable for detecting intruders at distances required for many intruder detection applications.

In some embodiments of the invention, VCSELs are used in systems with quadrature detection. However, quadrature detection requires knowing the direction of polarization of laser light provided by the laser. Polarization direction of light emitted by a VCSEL is not always known until the VCSEL has been installed in a system in which it is to function, and after installation the polarization direction may flip from one to the other of two orthogonal polarization directions. Therefore, in embodiments of the present invention using quadrature detection and a VCSEL, light emitted by the VCSEL is monitored so that its direction of polarization is known when quadrature detection measurements are performed.

An aspect of some embodiments of the present invention relates to providing a system, hereinafter referred to as a "sentinel system" for protecting a valuable object, such as for example, a painting or artifact in a museum, against theft.

Laser intruder detection systems, in accordance with some embodiments of the present invention, provide sensitive discrimination between various different forms and magnitudes of motion. As a result, such detection systems are well suited for use as sentinel systems. They are capable of distinguishing everyday motions and vibrations of an object from motion indicating the object is being purloined and thereby can provide reliable protection of an object with a relatively low rate of false alarms. Furthermore, for a delicate artifact or object subject to damage by vibration they can be used to sound an alarm if vibrations of the object reach an intensity or rate of occurrence that is liable to damage the object.

An aspect of some embodiments of the present invention relates to providing a sentinel system, hereinafter referred to as a "lifeguard sentinel", for monitoring status and well being of

a person, such as for example a sleeping baby or a bed ridden or wheel chair patient, by monitoring the person's motion.

A lifeguard sentinel, in accordance with an embodiment of the present invention comprises a laser intruder detection system in accordance with an embodiment of the present invention adapted to monitor motion of a person and detect aberrations in the motion. If a motion aberration is detected the lifeguard sentinel generates an appropriate alarm. For example, the lifeguard sentinel might be used to monitor breathing of a baby sleeping in a crib. The sentinel is positioned over the baby's crib and senses breathing motions of the baby. If the motions cease or otherwise exhibit aberrance indicative of a problem demanding attention, the sentinel raises an alarm.

There is therefore provided in accordance with an embodiment of the present invention a motion detector for detecting motion of a body in a surveillance zone comprising: at least one laser that produces laser light; at least one photodetector that generates signals responsive to light incident thereon; a light distributor that receives laser light from a laser of the at least one laser and distributes a portion of the light into a plurality of sensor light beams that extend into the surveillance zone and a portion of the light into at least one reference light beam that is incident on a region of the at least one photodetector, wherein the distributor is positioned and configured so that light reflected from a sensor beam by an object in the surveillance zone is received by the distributor and directed onto said region of the at least one photodetector; and circuitry that receives signals generated by the at least one photodetector and processes the signals to determine if reflected light incident on the at least one detector is Doppler shifted as a result of motion of the body, and if so, generates a signal indicating motion of the body.

Optionally the at least one reference beam is formed by light that is back distributed by the distributor. Additionally or alternatively, the plurality of sensor beams is optionally formed by light that is forward distributed by the distributor.

In some embodiments of the present invention, for each sensor beam of the plurality of sensor beams produced by the distributor the distributor produces a mirror image reference beam.

In some embodiments of the present invention, the distributor comprises a surface on which light received from the at least one laser is incident, which surface has a partially reflecting layer that controls how much of the light from the at least one laser is distributed to the at least one reference beam and how much is distributed to the plurality of sensor beams.

In some embodiments of the present invention, the distributor comprises a diffraction grating.

There is further provided, in accordance with an embodiment of the present invention, a motion detector for detecting motion of a body in a surveillance zone comprising: at least one laser that produces laser light; at least one photodetector that generates signals responsive to light incident thereon; a diffraction grating that receives laser light from the at least one laser and distributes a portion of the light into at least one sensor light beam that extends into the surveillance zone and a portion of the light into at least one reference light beam that is incident on a region of the at least one photodetector, and the light distributor is positioned and configured so that light reflected from a sensor beam by an object in the surveillance zone is received by the light distributor, and distributed onto said region of the at least one photodetector; circuitry that receives signals generated by the at least one photodetector and processes the signals to determine if reflected light incident on the at least one detector is Doppler shifted as a result of motion of the body, and if so, generates a signal indicating motion of the body; and wherein the light distributor comprises a diffractor. Optionally the at least one sensor beam comprises a plurality of sensor beams.

In some embodiments of the present invention, the plurality of sensor beams comprises at least three sensor beams and at least three of the sensor beams are coplanar. In some embodiments of the present invention, the plurality of sensor beams comprises at least three sensor beams and at least one of the plurality of sensor beams is not coplanar with at least two of the other sensor beams.

In some embodiments of the present invention, the at least one reference beam comprises a plurality of reference beams. Optionally the at least one photodetector comprises a plurality of photodetectors. Preferably, a different one of the plurality of reference beams is incident on each photodetector.

In some embodiments of the present invention, the at least one photodetector is a single photodetector.

In some embodiments of the present invention, the motion detector comprises a motor or actuator that cyclically moves the light distributor back and forth in a given direction so that frequency of light in the at least one reference beam is shifted by a predetermined frequency shift.

In some embodiments of the present invention, the motion detector comprises an optical frequency shifter through which light reflected from the body passes, which optical frequency shifter generates a predetermined frequency shift in the frequency of the reflected light.

Additionally or alternatively, the predetermined frequency shift is preferably greater than an expected Doppler shift of the reflected light caused by motion of the body. Preferably,

the circuitry processes signals from the at least one photodetector to determine a frequency difference between the frequency of a reference beam of the at least one reference beam and the frequency of the reflected light and determines that a component of motion of the body that generates the Doppler shift is in a first direction if the frequency difference is greater than the predetermined difference and in a second direction, opposite the first direction, if the frequency difference is less than the predetermined frequency difference.

In some embodiments of the present invention, the motion detector comprises a first and a second linear polarizer through which light that is incident on a first and a second photodetector respectively of the plurality of photodetectors passes. Preferably, directions of polarization axes of the first and second polarizers are not parallel. Optimally, the polarization axes of the first polarizer is substantially orthogonal to the axes of polarization of the second polarizer.

In some embodiments of the present invention, the reference beams that are incident on the first and second photodetectors are generated by the distributor from light from a same laser of the at least one laser, which laser provides linearly polarized light. Optionally, the motion detector comprises a polarization detector that detects the direction of polarization of the light from the laser.

Additionally or alternatively an angle between the polarization direction of the first linear polarizer and the polarization direction of the laser light is, optionally, substantially equal to 45^{o}.

In some embodiments of the present invention, the motion detector comprises a circular polarizer that circularly polarizes the reflected light. In some embodiments of the present invention, the motion detector comprises a circular polarizer that circularly polarizes light in the reference beams.

In some embodiments of the present invention, the first and second photodetectors respectively generate first and second signals responsive to reflected light and reference beam light incident on them, which first and second signals comprise, respectively, first and second signal components having a frequency equal to the Doppler frequency shift of the reflected light caused by motion of the body.

In some embodiments of the present invention, a photodetector of the at least one photodetector is a polarization sensitive photodetector sensitive to light in first and second directions of polarization, which photodetector generates first and second signals that are substantially independent of each other responsive to intensity of light incident on the

photodetector having a polarization direction parallel respectively to the first and second directions.

Optionally, the motion detector comprises a circular polarizer that circularly polarizes the reflected light. Alternatively, the motion detector optionally comprises a circular polarizer that circularly polarizes light in the reference beams.

In some embodiments of the present invention, the polarization sensitive photodetector receives light from a single reference beam and reflected light from a sensor beam, both reference and sensor beams being generated by light from a same single laser of the at least one laser, and wherein the first and second signals have first and second signal components characterized by a frequency equal to a Doppler frequency shift of the reflected light caused by motion of the body.

In some embodiments of the present invention, the circuitry determines which of the first and second signal components leads the other and if the first signal component leads the second signal component determines a first direction for a component of motion of the body that generates the Doppler shift and if the second signal component leads the first signal component determines a second direction for the component of motion which second direction is opposite the first direction.

In some embodiments of the present invention, the at least one laser comprises a plurality of lasers. Optionally, at least one of the lasers of the plurality of lasers provides light having a wavelength different from light provided by another laser of the plurality of lasers.

In some embodiments of the present invention light provided by a laser of the at least one laser is IR light.

In some embodiments of the present invention, the motion detector comprises at least one source of visible light, wherein when the at least one source is turned on, light from the source illuminates at least one region of the surveillance zone that is illuminated by light from a sensor beam of the at least one sensor beam.

In some embodiments of the present invention, the at least one reference beam does not extend into the surveillance zone.

There is further provided in accordance with an embodiment of the present invention an intruder detection system for detecting presence of an intruder in a surveillance zone comprising a motion detector according to an embodiment of the present invention wherein if the motion detector senses motion of a body in the surveillance zone, the circuitry determines if the Doppler shift is characteristic of motion of an intruder, and if it does generates a signal indicating presence of an intruder in the surveillance zone.

There is further provided in accordance with an embodiment of the present invention apparatus for guarding an object against theft or damage comprising a motion detector according to an embodiment of the present invention wherein at least one sensor beam of the motion detector is incident on the object and, if the object exhibits aberrant motion, generates an alarm.

There is further provided in accordance with an embodiment of the present invention apparatus for monitoring health status of a person comprising a motion detector according to an embodiment of the present invention wherein at least one sensor beam of the motion detector is incident on the person and, if the person exhibits aberrant motion, generates an alarm. In some embodiments of the present invention the person is a baby and a sensor beam of the motion detector is incident on the baby so as to detect breathing motions of the baby and if the breathing motions exhibit aberrance generates an alarm.

There is further provided in accordance with an embodiment of the present invention a method of detecting motion of an object in a surveillance zone comprising: diffracting light from a laser of at least one laser to generate at least one sensor beam of laser light that illuminates the surveillance zone; receiving light from a sensor beam of the at least one sensor beam that is reflected by the object; and determining whether the received light is Doppler shifted by a frequency generated by a component of motion of the object.

There is further provided in accordance with an embodiment of the present invention a method of detecting motion of an object in a surveillance zone comprising: generating a plurality of sensor beams of laser light from light provided by a laser that illuminate the surveillance zone; receiving light from a beam of the plurality of beams that is reflected by the object; and determining whether the reflected light is Doppler shifted by a component of motion of the object.

Optionally, generating a plurality of sensor beams comprises diffracting light from the laser.

In some embodiments of the present invention, determining a Doppler shift comprises generating at least one reference light beam from light provided by the laser and determining whether the reflected light is Doppler shifted with respect to the light in a reference beam of the at least one reference beam.

Optionally, generating at least one reference beam comprises diffracting light from the laser. Alternatively or additionally the at least one reference beam optionally comprises a plurality of reference beams.

There is further provided in accordance with an embodiment of the present invention a method of detecting motion of an object in a surveillance zone comprising: generating at least one sensor beam of laser light from light provided by a laser that illuminates the surveillance zone; generating a plurality of reference beams of light from a portion of the light provided by the laser; receiving light from a sensor beam of the at least one sensor beam, which is generated from light from the laser, that is reflected by the object; and determining whether the reflected light is Doppler shifted with respect to light in each of the reference beams by a component of motion of the object.

In some embodiments of the present invention, determining a Doppler shift comprises: coherently mixing the reflected light with light from at least one reference beam to generate at least one mixed signal; and determining whether the at least one mixed signal comprises a signal component having a frequency equal to a Doppler frequency shift characteristic of a component of motion of the object.

In some embodiments of the present invention, the method comprises introducing a predetermined offset frequency shift in the received light that is larger than an expected Doppler shift generated by a component of motion of the object, so that the received light has a difference in frequency with respect to the reference beam light that is equal to the sum of the offset frequency shift and the Doppler shift generated by the component of motion of the object.

In some embodiments of the present invention, the method comprises introducing a predetermined offset frequency shift in reference beam light that is larger than an expected Doppler shift generated by a component of motion of the object, so that a difference in frequency between the received light and the reference light is equal to the sum of the offset frequency shift and the Doppler shift generated by the component of motion of the object.

In some embodiments of the present invention, the method comprises determining a direction of the component of motion of the object that generates the Doppler shift responsive to whether the magnitude of the difference in frequency between the received light and the reference light is greater than or less than the offset frequency shift.

In some embodiments of the present invention, light provided by the laser is linearly polarized and the method comprises circularly polarizing at least a portion of the reflected light. Preferably, the method comprises linearly polarizing light in a first and second reference beam of the plurality of reference beams in first and second directions respectively. Preferably, the method comprises linearly polarizing first and second portions of the circularly polarized reflected light in the first and second directions and coherently mixing the first and second

portions of the reflected light with light in the first and second reference beams respectively so as to generate first and second mixed signals.

In some embodiments of the present invention, light provided by the laser is linearly polarized and the method comprises circularly polarizing light in a first and a second reference beam of the plurality of reference beams. Preferably, the method comprises linearly polarizing first and second portions of the reflected light in first and second directions respectively. Preferably, the method comprises linearly polarizing the circularly polarized light in the first and second reference beams in the first and second directions respectively and coherently mixing the linearly polarized reference beam light with the first and second portions of the reflected light respectively so as to generate first and second mixed signals.

In some embodiments of the present invention, in which first and second mixed signals are generated, the method comprises determining first and second signal components respectively of the first and second mixed signals that have a frequency equal to the Doppler shift of the received light. Preferably, the method comprises determining a direction of the component of motion of the object that generates the Doppler shift responsive to which of the first and second signal components leads the other.

In some embodiments of the present invention, the laser provides linearly polarized light and the method comprises: circularly polarizing light from the laser or the reflected light; mixing the circularly polarized laser or reflected light with, respectively, the reflected or laser light that has not been circularly polarized; generating first and second mixed signals responsive to mixed light in first and second polarization directions respectively; determining first and second signal components respectively of the first and second mixed signals that have a frequency equal to the Doppler shift of the received light; and determining a direction of the component of motion of the object that generates the Doppler shift responsive to which of the first and second signal components leads the other.

In some embodiments of the present invention, the method comprises detecting the direction of polarization of the linearly polarized light provided by the laser.

There is further provided a method for determining presence of an intruder in a surveillance zone comprising detecting motion of the intruder using a method in accordance with an embodiment of the present invention.

There is further provided a method for monitoring status of an object in a surveillance zone comprising detecting motion of the object using a method in accordance with an embodiment of the present invention and, if the object exhibits aberrant motion generating a signal indicating the occurrence of the aberrant motion.

There is further provided a method for monitoring health and status of a person in a surveillance zone comprising detecting motion of the person using a method in accordance with an embodiment of the present invention and, if the person exhibits aberrant motion, generating a signal indicating the occurrence of the aberrant motion.

BRIEF DESCRIPTION OF FIGURES

Non-limiting embodiments of the present invention are described below with reference to figures attached hereto. In the figures identical structures, elements or parts which appear in more than one figure are labeled with the same numeral in all the figures in which they appear. Dimensions of components and features shown in the figures are chosen for convenience and clarity of presentation and are not necessarily shown to scale. The figures are listed below.

Fig. 1 schematically shows a laser intruder detection system detecting an intruder, in accordance with an embodiment of the present invention;

Fig. 2 schematically shows a cross-sectional view of a laser intruder detection system comprising a plurality of lasers, in accordance with an embodiment of the present invention;

Fig. 3 schematically shows a cross-sectional view of another laser intruder detection system comprising a plurality of lasers in accordance with an embodiment of the present invention;

Fig. 4A schematically shows a laser intruder detection system, which uses quadrature detection, detecting an intruder, in accordance with an embodiment of the present invention;

Fig. 4B schematically shows an optical module for determining the polarization direction of laser light used in the intruder detection system shown in Fig. 4A, in accordance with an embodiment of the present invention;

Fig. 5 shows a block diagram of a circuit, in accordance with an embodiment of the present invention, used to process signals in the laser detection system shown in Fig. 4B;

Fig. 6 schematically shows a laser detection system protecting a room in accordance with an embodiment of the present invention;

Fig. 7 schematically shows a laser detection system being used as a sentinel system to protect a valuable picture, in accordance with an embodiment of the present invention; and

Fig. 8 shows a lifeguard sentinel being used to monitor a seeping baby, in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF EMBODIMENTS

Fig. 1 schematically shows a cross sectional view of a laser detection system 20 detecting the presence of an intruder 22 in a surveillance zone (the boundaries of which are not indicated in Fig. 1), in accordance with an embodiment of the present invention. In Fig. 1, for

convenience of presentation, intruder 22 is shown vertical, whereas the cross-section of detection system 20 shown in the figure is taken through a horizontal plane perpendicular to the posture of the intruder.

Detection system 20 comprises a laser 24, two photodetectors 26 and 28 and a diffractor 30. A controller 31 controls laser 24 and receives output signals from photodetectors 26 and 28 generated responsive to light incident on the photodetectors.

Laser 24 preferably has a coherence length substantially equal to or greater than twice a maximum distance for which intruders are to be detected. For example, if it is desired to detect intruder 22 at a distance of five meters, laser 24 preferably has a coherence length that is equal to or greater than ten meters. In some embodiments of the present invention, laser 24 radiates infrared light, for example, light having a wavelength of 850nm or 980nm. For many intruder detection applications, a power rating of approximately 1 milliwatt for laser 24 is sufficient. In some embodiments of the present invention, laser 24 is a vertical cavity surface emitting laser (VCSEL) that is operated in single-mode in order to obtain a required coherence length.

Laser light, represented by bold arrowed lines 32, is radiated by laser 24 and is collimated by a collimating lens 34. The light is directed so that it is incident on a surface 36 of diffractor 30. Some of laser light 32 is back-diffracted from surface 36 and some is transmitted through surface 36 and forward diffracted by diffractor 30. Optimally, surface 36 is coated with an appropriate metallic or dielectric layer (not shown) that determines the ratio of the amount of incident laser light 32 that is back-diffracted to the amount of incident laser light 32 that is forward diffracted. Preferably, only a small portion of incident laser light 32 is back-diffracted. In some embodiments of the present invention, diffractor 30 comprises an amplitude grating that diffracts laser light 32 by modulating the amplitude of incident laser light 32. In some embodiments of the present invention, diffractor 30 comprises a phase grating that diffracts laser light 32 by modulating the phase of incident laser light 32.

Some of the light that is back-diffracted by diffractor 30 is diffracted into beams of laser light, represented by dashed arrowed lines 40 and 42, that are directed towards photodetectors 26 and 28 respectively. Beams of laser light 40 and 42 are reference beams of intruder detection system 20. Light from these reference beams are focused onto spots (not shown) on photodetectors 26 and 28 respectively by lenses 44 and 46. In some embodiments of the present invention, photodetectors 26 and 28 are protected by irises 48 and 49 respectively that have openings, for example, approximately the size of spots to which light in reference beams 40 and 42 is focused on photodetectors 26 and 28. Irises 48 and 49 reduce the amount of background light incident on photodetectors 26 and 28. In addition, photodetectors 26 and 28

are optionally shielded by filters (not shown) that transmit substantially only light having a wavelength the same as that of laser light 32.

In some embodiments of the present invention, photodetectors 26 and 28 are small and do not require irises 48 and 49. In addition smaller photodetectors generally have smaller capacitance and dark currents than larger photodetectors, both of which attributes improve signal to noise.

Laser light that is transmitted by diffractor 30 is diffracted into multiple sensor beams of laser light represented by arrowed lines 50, 51 and 52. Sensor beams 50, 51 and 52 extend into the volume of the surveillance zone protected by intruder detection system 20. Reference and sensor beams 40, 42, 50, 51 and 52 are coherent with each other.

A portion (not shown) of laser light 32 that is back diffracted by diffractor 30 is incident on laser 24. This is generally undesirable. In addition, preferably, intensity of light in sensor beams 50, 51 and 52 is substantially the same. Diffractor 30 can optimally be designed so that back diffracted light that reaches laser 24 is minimized and intensity of light in forward-diffracted sensor beams is substantially the same. This can be achieved using the difference between phase relations in grating orders of back-diffracted and forward-diffracted light of a grating, as is well known in the art of diffraction grating and holographic design.

Intruder 22 is shown, by way of illustrative example, illuminated by sensor beam 51 and moving towards diffractor 30 with a velocity "V_I" represented by double arrow 60. Light, represented by wavy arrows 62, from sensor beam 51 is reflected by intruder 22 back towards diffractor 30 where it is forward-diffracted towards photodetectors 26 and 28. Reflected light 62 is focused onto photodetectors 26 and 28 by the same lenses 44 and 46 respectively that focus reference beams 40 and 42 on photodetectors 26 and 28. (Some of reflected laser light 62 is also forward-diffracted towards laser 24, however as a result of its relatively low intensity, the forward-diffracted light reaching laser 24 does not practically affect the laser's performance.)

Preferably, diffractor 30 is designed so that the spatial configuration of the sensor laser beams is a mirror image of the spatial configuration of reference laser beams. The reference and sensor laser beams of intruder detection system 20 have mirror image spatial configurations. However, in Fig. 1 a reference beam, whose intensity is preferably minimized, that is a mirror image of sensor beam 51 is not shown in the interests of simplicity of presentation. The back-diffracted "reference" beam not shown is a beam that back diffracts to the laser, and which is therefore not used as a reference beam. As a result of the mirror image configurations, light reflected by an intruder from any of sensor beams 50, 51 or 52 is

accurately focused to the same locations on photodetectors 26 and 28 to which light in reference beams 40 and 42 is focused.

When reflected light 62 reaches photodetector 26, photodetector 26 generates a signal responsive to the energy received from both reflected light 62 and from reference beam light 40. Similarly, when reflected light 62 reaches photodetector 28, photodetector 28 generates a signal responsive to energy received from both reflected light 62 and from reference beam light 42. The output signals from both photodetectors comprise Doppler shift components, *i.e.* Doppler signals, that are in phase with each other and proportional to $\cos(2\omega_0 V_I t/c + \phi) = \cos(\omega_D t + \phi)$. In the formula, ω_0 is the frequency of laser light 32, c is the velocity of light, ϕ is a phase angle generated by a difference in optical path length to photodetectors 26 and 28 for reference beam light 40 and 42 respectively and reflected light 62, ω_D is the Doppler frequency shift in reflected light 62 caused by V_I and t is time.

It should be realized that only reflected light 62 that is incident on areas of photodetectors 26 and 28 on which light from reference beams 40 and 42 is incident contributes to a Doppler signal. Reference beam light and reflected beam light that are incident on different areas of photodetectors 26 or 28 contribute only to DC components of signals generated by photodetectors 26 and 28.

To assure proper overlapping of intruder reflected light and reference light on photodetectors 26 and 28, the diffraction angle of laser light 32 should optimally be less than the dispersion angle of reflected light 62. If α is the diffraction angle of laser light 32, $\alpha = k\lambda/W$ where λ is the wavelength of laser light 32, W is the beam width of collimated laser light 32 and k is a geometrical coefficient depending upon the shape of the collimated beam. If β is the dispersion angle of reflected light 62 reaching photodetectors 26 and 28 then $\beta = W/L$, where L is the distance of intruder 22 from diffractor 30. Therefore, to assure proper overlap, preferably $\beta > \alpha$, which leads to a condition that $W > (k\lambda L)^{1/2}$. By way of example, for λ = 850nm and L = 4 meters W should be greater than about 2 mm.

The output signals generated by photodetectors 26 and 28 are transmitted to controller 31 where they are processed using methods known in the art to determine their component Doppler signals and the Doppler frequency ω_D. In some embodiments of the present invention, ω_D is determined from a sum of output Doppler signals from photodetectors 26 and 28. In some embodiments of the present invention, the outputs of photodetectors 26 and 28 are electrically connected together before they are input to controller 31 in order to sum their

Doppler signals. By using a sum of Doppler output signals, signal to noise is increased and accuracy of a determined value for ω_D improved.

In order to improve signal to noise, in some embodiments of the present invention, one or more reference beams in an intruder detection system are focused onto a same region of a single photodetector using an appropriate combination of prisms, mirrors and/or common optical components. Intruder reflected light that is diffracted to coincide with the reference beams is therefore also focused to the same area on the photodetector. A single photodetector therefore collects and heterodynes reference light and reflected light that would otherwise be collected and heterodyned by at least two photodetectors.

If ω_D has a value in a range of expected values for an intruder, controller 31 generates a signal to initiate an action appropriate to a purpose for which intruder detection system 20 is being used, for example to trigger an alarm, open a door or turn on an air conditioner. In Fig. 1 intruder detection system is shown triggering an alarm 33 when intruder 22 is detected.

In some embodiments of the present invention, diffractor 30 is cyclically moved back and forth in directions indicated by double arrowhead line 70. The direction and magnitude of velocity of diffractor 30 are sensed by controller 31 and correlated with measurements of Doppler frequencies to determine a direction of motion of intruder 22. There are many and varied methods, in accordance with embodiments of the present invention for moving diffractor 30 back and forth and correlating motion of the diffractor with Doppler frequency measurements. For example, in some embodiments of the present invention, a piezoelectric motor is used to move diffractor 30 back and forth along double arrowhead line 70. The piezoelectric motor is controlled to move diffractor 30 with a substantially constant accurately controlled velocity in a "forward" direction along double arrowed line 70 from a suitable first position to a second position. When diffractor 30 reaches the second position the piezoelectric motor is controlled to rapidly snap diffractor 30 back to the first position and begin the cycle again. Controller 31 monitors the motion cycle using methods known in the art, and Doppler shift measurements are made during times that diffractor 30 is being moved with the accurately controlled velocity in the forward direction. Alternatively, by way of another example, diffractor 30 may be moved back and forth harmonically and phases of the harmonic motion correlated with Doppler frequency measurements.

The motion of diffractor 30 does not affect the frequency of reflected light 62 however it does Doppler shift the frequency of reference beam light 40 and 42 incident on photodetectors 26 and 28. Assume for example that diffractor 30 is moving towards laser 24 with a velocity V_d when reflected light 62 and reference beam light 40 and 42 are heterodyned

by photodetectors 26 and 28 respectively. If intruder 22 is not moving, Doppler signals from photodetectors 26 and 28 are proportional to $\cos(2\omega_o V_d t/c + \phi)$ and a Doppler frequency ω_D for the Doppler signals will be determined to be equal to $\omega_d = 2\omega_o V_d/c$. If intruder 22 has a component of velocity V_I in a same or opposite direction as V_d, the Doppler frequency ω_D will be determined to have a value equal to $2\omega_o(|V_d| - |V_I|)$ or $2\omega_o(|V_d| + |V_I|)$ respectively. Thus, if intruder 22 is moving in a same direction as V_d (*i.e.* V_I and V_d are in the same direction), the Doppler frequency ω_D is less than ω_d and if intruder 22 is moving in a direction opposite to V_d (*i.e.* V_I and V_d are in opposite directions), ω_D is greater than ω_d. To insure discrimination between motion of an intruder towards and away from diffractor 30, preferably, $|V_d|$ is chosen sufficiently larger than the magnitudes of velocities that characterize motion of an intruder so that $(|V_d| - |V_I|)$ is greater than zero for substantially all intruder velocities V_I. Therefore, in accordance with an embodiment of the present invention, controller 31 determines the direction of V_I using a known direction and magnitude for V_d and a value determined for the Doppler frequency ω_D.

Intruder detection system 20 is shown with only two photodetectors and associated reference beams and only three sensor laser beams for clarity of exposition. Intruder detection systems, in accordance with some embodiments of the present invention, can have a number of photodetectors and associated reference laser beams other than two and a number of sensor laser beams other than three. In many situations, it may be necessary or desirable for an intruder detection system, in accordance with an embodiment of the present invention, to have more or less than three sensor beams to protect the volume of a particular surveillance zone. A diffractor required for practically any desired number of photo-sensors and number and spatial pattern of reference and sensor beams for an intruder detection system, in accordance with an embodiment of the present invention, can be provided using techniques, such as holographic techniques, that are well known in the art.

It should also be noted that while the various laser beams comprised in intruder detection system 20 are indicated as being coplanar, intruder detection systems, in accordance with an embodiment of the present invention comprising non-coplanar sensor and/or reference beams are possible and can be advantageous. Various two dimensional diffractors for diffracting a laser beam into a desired non-coplanar pattern of laser beams are well known in the art. Such two-dimensional diffractors can be used, in accordance with an embodiment of the present invention, to provide desired patterns of reference and sensor beams, for example,

vertical and horizontal distributions of reference and sensor beams, for protecting the volume of a surveillance zone.

In some cases where a sensor beam configuration comprising many sensor beams is required to provide protection for a surveillance zone, a single laser might not be able to provide sufficient energy for all the sensor beams. Therefore in intruder detection systems, in accordance with some embodiments of the present invention, a plurality of lasers is used to provide a desired configuration and intensity of reference and sensor beams.

Fig. 2 schematically shows, by way of example, a side cross-sectional view of an intruder detection system 300, in accordance with an embodiment of the present invention, comprising more than one laser. Intruder detection system 300 optionally comprises first and second lasers 301 and 302, a linear diffractor 304 having grating lines 306 characterized by a grating pitch Λ and a collimating lens 308 having an optic axis 310 for focusing light from lasers 301 and 302 on the diffractor. For convenience of presentation and to prevent clutter, only sensor beams and elements of intruder detection system 300 pertinent to the discussion of the sensor beams are shown. Detectors used to sense reference beams and reflected sensor beam light are positioned similarly to the manner in which detectors shown in Fig. 1 are positioned and are not shown for intruder detection system 300.

Lasers 301 and 302 are optimally located on a focal plane 312 of lens 308 along a line formed by the intersection of focal plane 312 and a plane perpendicular to grating lines 306 that contains optic axis 310. By way of example, laser 301 is located on optic axis 310 and laser 302 is positioned so that a line 314 from the center of lens 308 to the position of laser 302 forms an angle β with the optic axis. Solid lines represent light from laser 301 and light from laser 302 is represented by dashed line.

If α_n (where n is an integer) is the angle of the n-th grating order for light radiated by laser 301 then the grating order angles of light from the laser are defined by the relation, $\sin(\alpha_n) = n\lambda/\Lambda$, where λ is the wavelength of light radiated by the laser. Light from laser 301 is forward diffracted into sensor beams 321, each one of which is defined by a grating order of the light that is indicated in parentheses in the sensor beam.

Grating order angles α_n for laser 302 are defined by the relation $\sin(\alpha_n) + \sin(\beta) = n\lambda/\Lambda$. By way of example, in Fig. 2 it is assumed that $\beta = \sin^{-1}(\lambda/2\Lambda)$. As a result, the grating order angles for light from laser 302 are defined by $\sin(\alpha_n) = (n-1/2)\lambda/\Lambda$ and occur substantially midway between the grating order angles of light from laser 301. Forward-

diffracted light from laser 302 therefore generates sensor beams 322 each one of which is located midway between two adjacent sensor beams 321 generated by light from laser 301.

Some laser intruder detection systems in accordance with embodiments of the present invention comprise a plurality of lasers each of which emits light having a wavelength different from the wavelengths of light emitted by the other lasers of the plurality of lasers. Light of different wavelengths diffract at different angles form a diffraction grating. Therefore to generate a desired configuration of sensor and reference beams, in accordance with an embodiment of the present invention, it can be advantageous to use laser light of different wavelengths.

By way of example assume a laser intruder system configured similar to laser intruder system 300 shown in Fig. 2 comprising a plurality of lasers, each of which emits light characterized by a different wavelength. Assume that the i-th laser of the plurality of lasers emits light having a wavelength λ_i and that the i-th laser is located at an angle $\beta_i = \sin^{-1}[\lambda_i/(2\Lambda)]$ (using the same coordinate conventions as in Fig. 2). The i-th laser will then generate a pattern of reference and sensor beams defined by grating angles $(n-1/2)\lambda_i/\Lambda$. While the configurations of reference and sensor beams for all the lasers are similar, since the wavelengths λ_i are all different, the configurations are shifted one from the other and do not in general overlap. If there are a total of N lasers, the intruder detection system will comprise N distinct non-overlapping reference and sensor beam configurations, each powered by its own laser and each characterized by a different wavelength of light.

Fig. 3 schematically shows a side view of another intruder detection system 330, in accordance with an embodiment of the present invention, comprising two lasers 332 and 334 that emit light at wavelengths λ_1 and λ_2 respectively. As in Fig. 2, in Fig. 3, for convenience of presentation and to prevent clutter, only sensor beams and elements of intruder detection system 300 pertinent to the discussion of the sensor beams are shown. Light detectors are not shown.

Intruder detection system 330 is similar to laser intruder detection system 300. Lasers 332 and 334 are respectively located on focal plane 312 at angles $\beta_1 = \sin^{-1}[\lambda_1/(2\Lambda)]$ and $\beta_2 = \sin^{-1}[\lambda_2/(2\Lambda)]$. Light from laser 331 is forward diffracted into sensor beams 341, which are shown in dashed lines. Light from laser 332 and its corresponding sensor beams 342 are shown in solid lines. Sensor beams 341 and sensor beams 342 are shifted one from the other and angular separations between adjacent sensor beams 341 are different from angular separations

between adjacent sensor beams 342 as a result of the difference in their wavelengths and choice of angles.

It is to be noted that the use of different wavelengths in an intruder detection system in accordance with an embodiment of the present invention can be advantageous from considerations other than providing a desired sensor beam configuration. For example, clothes worn by an intruder might for example reflect light of one wavelength weakly and light of a second wavelength strongly or ambient light might reduce signal to noise in one wavelength but not in another.

In some embodiments of the present invention, a non-planar spatial configuration of reference and sensor beams is provided by forming a laser intruder detection system from sub-units, each of which is a laser detection system that provides a planar distribution of reference and sensor beams. For example, a laser intruder detection system may comprise a plurality of sub-units, each of which is a laser detection system 20 shown in Fig.1. The sub-units may for example be "stacked" one on top of the other with the planes of their respective sensor beams 50, 51 and 52 (Fig. 1) parallel or tilted with respect to each other to form various configurations of sensor beams.

Whereas, as noted above, almost any "static" pattern of sensor beams, in accordance with an embodiment of the present invention, required to protect a surveillance zone can be provided, it may be desirable or advantageous to scan a surveillance zone with a pattern of sensor beams. Therefore, in some embodiments of the present invention, a spatial configuration of sensor beams is moved to scan the volume of a surveillance zone. For example, components of intruder detection system 20 may be mounted in an appropriate housing that is mechanically rotated about at least one axis or translated along at least one axis to move sensor beams 50, 51 and 52 and thereby scan the volume of a surveillance zone protected by intruder detection system 20.

Fig. 4A schematically shows another intruder detection system 100, detecting the presence of intruder 22 in a surveillance zone protected by intruder system 100, in accordance with an embodiment of the present invention. Intruder detection system 100 is similar to intruder detection system 20 shown in Fig. 1. However, intruder detection system 100 is designed to determine a direction of motion of intruder 22 using quadrature detection.

Intruder detection system 100 comprises a laser 24 that emits laser light 32 and two photodetectors 26 and 28. A linear polarizer 102 and optionally, an iris 48 are positioned in front of photodetector 26 and a linear polarizer 104 and optionally, an iris 49 are positioned in front of photodetector 28. Preferably, the polarization transmission axes of polarizers 102 and

104 are orthogonal. (A polarization transmission axis of a polarizer is defined as a direction in the polarizer that is parallel to the polarization vector of light that passes through the polarizer.) As in the case of intruder detection system 20, if photodetectors 26 and 28 of intruder detection system 100 are sufficiently small, irises 48 and 49 are not necessary. Optionally photodetectors 26 and 28 are protected by appropriate filters that transmit substantially only light having a wavelength the same as that of laser light 32.

Laser light 32 from laser 24 is optimally collimated by a lens 106 and back and forward-diffracted by a diffractor 30. Diffractor 30 is for example, a linear diffractor, which, in the perspective of Fig. 4A has grating lines perpendicular to the plane of Fig. 4A. Surface 36 of diffractor 30 is, preferably, coated with an appropriate metallic or dielectric layer, as is known in the art, to control the ratio of the amount of light from laser light 32 that is back-diffracted to the amount of light from laser light 32 that is forward-diffracted.

In some embodiments of the present invention, diffractor 30 comprises a binary reflecting amplitude grating in which the width and reflectivity of reflecting lines determines the power ratio of the diffracted beams and the ratio of energy in forward diffracted to back-diffracted light. In some embodiments of the invention, the diffractor is a phase grating, such as a binary phase grating formed from plastic. The ratio of energy in back-diffracted to forward-diffracted light and the power ratio between diffracted orders may be controlled, as is known in the art, by properly selecting diffraction groove shape and depth and the indices of refraction of materials used in the grating.

Back-diffracted light is diffracted into reference beams 40 and 42. Light in reference beams 40 and 42 is preferably focused by lens 106 onto photodetectors 26 and 28 respectively. Light in reference beams 40 and 42 pass through linear polarizers 102 and 104 before being incident on photodetectors 26 and 28 respectively. Forward-diffracted light passes through a quarter wave plate 140 and a linear polarizer 142 and form sensor beams 50, 51 and 52.

To understand the operation of intruder detection system 100 assume, by way of example, that laser 24 is positioned so that the polarization vector of laser light 32 is oriented at an angle of 45° with respect to the normal to the plane of Fig. 4A. As a result, the polarization vectors of light in reference beams 40 and 42 are also substantially orientated at 45° with respect to the normal. In some embodiments of the present invention, the polarization transmission axes of polarizers 102 and 104 are oriented at 45° with respect to the polarization vectors of light in reference beams 40 and 42 (*i.e.* parallel and perpendicular to the plane of Fig. 2). As a result, the intensity of reference beam light 40 on photodetector 26 is substantially the same as the intensity of reference beam light 42 on photodetector 28.

A pertinent direction associated with a component or feature of an element in Fig. 4A is shown by a rubric in a circular "cross-hair" icon connected to the feature or element by a line. A bold line is used to indicate a polarization transmission axis of a polarizer and a bold arrow indicates the direction of a polarization vector. Circular polarization is indicated by a circle with an arrowhead pointing anti-clockwise or clockwise to indicate respectively right or left hand circularly polarized light. Directions are shown relative to the perpendicular to the plane of Fig. 4A which is represented by a "12 o'clock line" in icon 120.

Icons 122, 124 and 126 schematically show directions, optionally used in the practice of the present invention, of the polarization vectors of laser light 32 and light in reference beams 40 and 42 respectively. Icons 128 and 130 show directions of the polarization transmission axes of polarizers 102 and 104 respectively, that are, optimally, orthogonal. .Intruder 22 is illuminated, by way of example, by sensor beam 51 and reflects light 62 from sensor beam 51 toward diffractor 30. On its way to diffractor 30, reflected light 62, which is typically substantially randomly polarized after being reflected from intruder 22, passes through linear polarizer 142 and then through quarter wave plate 140. Quarter wave plate 140 and polarizer 142 together form a circular polarizer that circularly polarizes reflected light 62. After passing through quarter wave plate 140, reflected light 62 is circularly polarized, as indicated in icon 152. Circularly polarized reflected light 62 is then forward-diffracted by diffractor 30 and focused by lens 106 so that it passes through linear polarizers 102 and 104 and is incident on photodetectors 26 and 28 respectively. Because the polarization transmission axes of polarizers 102 and 104 are orthogonal, the polarization vectors of reflected light 62 reaching photodetectors 26 and 28 are orthogonal and reflected light 62 incident on photodetector 26 is phase shifted by $\pi/2$ radians from reflected light 62 incident on photodetector 28.

Assume that intruder 22 is moving in the surveillance zone with a component of velocity V_I, represented by double arrow 60, in a direction parallel to sensor beam 51. As in the case of intruder detection system 20, the movement of intruder 22 generates Doppler shifts in reflected light 62 that are used to detect the presence of intruder 22. However, because reflected light 62 incident on photodetector 26 is phase shifted with respect to reflected light 62 reaching photodetector 28, in accordance with an embodiment of the present invention, Doppler signals generated by photodetectors 26 and 28 are usable to determine directions of motion for intruder 22.

Let DS_{26} represent a Doppler signal from photodetector 26 and DS_{28} a Doppler signal from photodetector 28. Then $DS_{26} = A\cos(2\omega_o V_I t/c + \phi)$ and $DS_{28} = A\cos(2\omega_o V_I t/c + \phi + \pi/2)$, where ω_o is the frequency of laser light 32. (The amplitudes of DS_{26} and DS_{28} are

substantially the same because of the 45° angles between the polarization vector of laser light 32 and the polarization transmission axes of polarizers 102 and 104 and circular polarization of reflected light 62 which is incident on polarizers 102 and 104.)

DS_{26} and DS_{28} are a pair of quadrature signals. If V_I is positive, then DS_{26} is delayed by a quarter of a cycle with respect to DS_{28}. If V_I is negative, then DS_{26} leads DS_{28} by a quarter cycle. By determining which of signals DS_{26} and DS_{28} leads the other, the direction of V_I in accordance with an embodiment of the present invention is determined.

The polarization directions of light and the directions of polarization transmission axes used to illustrate the operation of intruder detection system 100 are chosen for ease of presentation and other "polarization combinations" that would function to provide quadrature detection are possible and will occur to persons of the art. For example laser light 32 may be circularly polarized and reflected light 62 polarized at 45°, *i.e.* laser light 32 and reflected light 62 "exchange roles".

It should also be noted that photodetectors 26 and 28 may be replaced by a single photodetector sensitive to light in two polarization directions that generates signals responsive to intensity of incident light in one of the polarization directions substantially independent of intensity of incident light in the other of the polarization directions. A single photodetector suitable for functioning in place of photodetectors 26 and 28, in accordance with an embodiment of the present invention, is described in PCT Application PCT/IL99/00705, the disclosure of which is incorporated herein by reference.

In some embodiments of the present invention, a diffractor of a type described in PCT Application PCT/ IL99/00669 with reference to Fig. 8 in the application replaces diffractor 30, quarter wave plate 140 and polarizer 142 in intruder detection system 100. The disclosure of PCT Application PCT/IL99/00669 is incorporated herein by reference. The described diffractor generates back-diffracted circularly polarized reference beams from linearly polarized laser light incident on the diffractor and forward-diffracted linearly polarized sensor beams from the laser light. The diffractor is relatively energy efficient, and except for light absorbed in the material from which the diffractor is formed, substantially all the laser light incident on the diffractor is either forward-diffracted or back-diffracted.

It should be noted that the leading and lagging Doppler signals DS_{26} and DS_{28} are reversed if the polarization vector of laser light 32 is perpendicular to the choice of direction shown in Fig. 4A. In order to determine a direction for V_I therefore it is necessary to know the direction of the polarization vector of laser light 32.

However, the polarization direction of light that some lasers radiate may change with time. For example, as noted above, the polarization direction of laser light from VCSEL lasers is apt to alternate between two orthogonal directions. In some embodiments of the present invention, therefore, the polarization direction of laser light 32 is monitored to determine a direction for its polarization vector. The determined direction is used by controller 31 in determining a direction for V_I.

The polarization of laser light 32 may be monitored, in accordance with embodiments of the present invention, using different techniques and optical components known in the art. Fig. 4B schematically shows an optical module 170, which has components shown inside a dashed rectangle, that is used to monitor the polarization direction of laser light 32 in intruder detection system 100 shown in Fig. 4A, in accordance with an embodiment of the present invention. In Fig. 4B only that portion of intruder detection system 100 necessary to describe the operation of module 170 is shown.

In some embodiments of the present invention, module 170 comprises a beam splitter 172, a linear polarizer 174 and a photodetector 176. Beam splitter 172 is preferably positioned between laser 24 and lens 106 so that while light emitted by laser 24 passes through beam splitter 172 in order to reach lens 106, beam splitter 170 doesn't interfere with reference beams 40 and 42. Most of the light in laser light 32 incident on beam splitter 172 is transmitted by beam splitter 172 to lens 106 and preferably only small portion, represented by arrowed lines 173, is reflected towards linear polarizer 174. The polarization transmission axis of polarizer 174 is preferably oriented so that when laser light 32 is polarized along a first of its two orthogonal polarization directions, substantially all the light from laser light 32 reaching polarizer 174 from beam splitter 172 is transmitted to photodetector 176. When laser light 32 is polarized along a second of its two orthogonal polarization directions, substantially no light from laser light 32 reaching polarizer 174 from beam splitter 172 is transmitted to photodetector 176. The magnitude of the output of photodetector 176 therefore indicates the polarization direction of laser light 32.

Fig. 5 shows a block diagram of an example of a circuit 200, in accordance with an embodiment of the present invention, comprised in controller 31 for processing output signals from photodetectors 26 and 28 in intruder detection system 100.

Circuit 200 comprises a processor 202 and signal-processing modules 204 and 206 that comprise components shown inside dashed rectangles labeled with the numeral of the module to which they belong. Signal processing module 204 receives signals 210 from photodetector 28 and provides processed output signals responsive to received signals 210 to processor 202.

Similarly signal-processing module 206 receives signals 212 from photodetector 26 and provides processed output signals responsive to signals 212 to processor 202. Modules 204 and 206 are optionally identical and components and operation of only module 204 will be described.

In some embodiments of the present invention, an output signal 210 received by module 204 from photodetector 28 is first amplified by a preamplifier 214 and then filtered by a band-pass filter 216. Band-pass filter 216 removes DC components from signal 210 that are generated by light from reference beam 42 and ambient light. Preferably, band-pass filter 216 transmits only frequencies in a desired band of frequencies characteristic of Doppler shift frequencies generated by an intruder moving in a surveillance zone of intruder detection system 100. In some embodiments of the present invention, frequency components of signal 210 transmitted by band-pass filter 216 are amplified a second time by an amplifier 218 and input to a circuit element 220, such as for example a Schmitt trigger, that converts input from amplifier 218 to logic signals. The logic signals are input to processor 202.

In addition, module 204 optionally comprises a circuit element 221 that receives input from band pass filter 216 and processes the input to generate logic signals responsive to the amplitude or power of signal 210 in the "Doppler frequency band" determined by the band pass filter. The generated logic signals are transmitted by circuit element 221 to processor 202.

In accordance with an embodiment of the present invention, circuit 200 comprises a module 230 for processing output signals 232 from photodetector 176, which is comprised in optical module 170 shown in Fig. 4B. As discussed above in the description of optical module 170, output signals from photodetector 176 indicates a direction for the polarization of laser light 32 used in intruder detection system 100 (Fig. 4A). A signal 232 from photodetector 176 is optimally amplified by an amplifier 234 and converted to a logic signal by a comparator 236, which logic signal is input to processor 202.

In some embodiments of the present invention, processor 202 processes signals from circuit elements 220 of modules 204 and 206 using quadrature detection algorithms well known in the art, and polarization directions determined from signals from module 170, to determine magnitudes and directions of velocities from the signals. Processors that perform quadrature detection required by intruder detection systems, in accordance with some embodiments of the present invention, are readily available commercially. A description of such commercially available processors and their mode of operation may be found in the Jan 1998 Honeywell Infrared Products catalogue pp. 407 – 412.

In some embodiments of the present invention, processor 202 analyzes determined magnitudes and directions to determine if they are consistent with motion of an intruder in the surveillance zone or that they represent stimuli that should be ignored. If they are consistent with motion of an intruder, circuit 200 generates a signal to initiate an appropriate response to the intruder, such as, if the intruder is unwelcome, sounding an alarm 240, or if the intruder is welcome, opening a door 242 or turning on an air conditioner 244.

Because intruder detection systems 20 (in versions that determine directions of velocities) and 100, determine both magnitudes and directions of velocities from signals generated by photodetectors 26 and 28, intruder systems 20 and 100 are sensitive to differences between sources that stimulate signals in photodetectors 26 and 28. For example, intruder detection systems 20 and 100 can relatively easily discriminate between vibratory motion of objects and structures in a surveillance zone and steady motion in a particular direction characteristic of motion of an intruder. As a result, intruder detection systems in accordance with embodiments of the present invention can provide reliable detection efficiencies with relatively low false alarm rates.

In some embodiments of the present invention, in addition to analyzing frequency of signals generated by photodetectors 26 and 28, a laser intruder detection system analyzes their amplitudes or power as well. Optionally, the detection system determines that an intruder is present only if frequency analysis of the signals determines that the signals comprise a Doppler shift component compatible with presence of an intruder and amplitude or power of the Doppler shift component is greater than an appropriate threshold. For example, in some embodiments of intruder detection system 100, processor 202 (Fig. 5) uses signals from circuit elements 221 of signal-processing modules 204 and 206 to analyze amplitudes and/or power of signals 210 and 212. Only if both frequency analysis of signals 210 and 212 and amplitude and/or power analysis of the signals indicate presence of an intruder does intruder detection system 100 determine that an intruder is present.

By imposing an amplitude and/or power criterion in addition to a frequency criterion in determining presence of an intruder, reliability of intruder detection and false alarm rates provided by a laser detection system in accordance with an embodiment of the present invention are further improved. However, in some embodiments of the present invention, a magnitude of motion of an intruder is not determined. In such embodiments, an intruder detection system determines that an intruder is present in a surveillance zone protected by the detection system responsive to results of analysis only of amplitude and/or power of a signal generated by the presence of an intruder in the surveillance zone.

Fig. 6 shows a schematic plan view of an intruder detection system 250 protecting a room 252, having walls 254 and a door 256, in accordance with an embodiment of the present invention. Laser light sensor beams 258 extend to span the volume of room 252 from a housing 255 comprising optical and electronic components (not shown) of detection system 250. Intruder detection system 250 can, for example, determine if door 256 is being opened or closed or if a person is moving in room 252 and generate signals to initiate appropriate responses thereto. It can also determine that signals that it receives are generated by vibrations in walls 254, which might for example be caused by the passage of a heavy vehicle in the vicinity of room 252, and "decide" to ignore the signals.

Intruder detection systems in accordance with some embodiments of the present invention, because of their capability to differentiate between different patterns of motion are useable as "sentinel" security systems to guard valuables such as paintings or artifacts in a museum. Sentinel security systems, in accordance with some embodiments of the present invention, may also be used to protect cars against theft.

Fig. 7 shows an intruder detection system, in accordance with an embodiment of the present invention, being used as a sentinel system 260 to guard a valuable painting 262 hung on wall 264. Sentinel system 262 optionally comprises a housing 266 from which a plurality of relatively closely spaced sensor beams 268 are emitted. Sensor beams 268 are incident on picture 262. Normal vibrations of picture 262, such as caused by people walking past picture 262 and air drafts moving through the room are detected by sentinel system 266 and ignored. However, if a thief were to attempt to remove the painting from wall 264, sentinel system 268 would determine that movement of picture 262 is anomalous and would sound an alarm. It should be realized that whereas sentinel system 260 illuminates picture 262 with a plurality of sensor beams 268 in some sentinel systems, in accordance with some embodiments of the present invention a single sensor beam is used to guard an object. A single sensor beam might be preferable to monitor motion along a single direction in space and can be provided by suitably blocking all but one sensor beam generated by a sentinel system, in accordance with an embodiment of the present invention.

Fig. 8 shows a healthguard sentinel 350 monitoring breathing of a baby sleeping in a crib 352 having a mattress 354. Sensor beams 356 from sentinel 350 spread out to illuminate a region of mattress 354 so that at least one sensor beam 356 illuminates the baby for substantially any location of the baby in the crib. Light reflected by the baby from the at least one sensor beam is analyzed to determine motion of the baby's body and in particular to determine the baby's thoracic motions and if such motions indicate cessation of breathing or

other aberrant motion indicative of respiratory stress. Healthguard sentinel 350 analyzes reflected sensor beam light to determine "baby motion" using methods similar to those used in embodiments of the present invention for detecting presence of an intruder or motion of an artifact as discussed above.

In some embodiments of the present invention, an intruder detection system or sentinel system, in accordance with an embodiment of the present invention, is equipped with at least one source of visible light. When turned on light from the at least one source illuminates at least one region in a surveillance zone protected by the system that is illuminated by a sensor beam of the at least one sensor beam. A user of the system can align the system responsive to the at least one region illuminated by the visible light.

In some embodiments of the present invention, a laser used to provide sensor beams in an intruder detection system or a sentinel system is pulsed and signals are sampled with a sample and hold circuit. This can substantially reduce power consumption of the system and also decrease sensitivity of the system to ambient light, as is well known in the art.

In the description and claims of the present application, each of the verbs, "comprise" "include" and "have", and conjugates thereof, are used to indicate that the object or objects of the verb are not necessarily a complete listing of members, components, elements or parts of the subject or subjects of the verb.

The present invention has been described using detailed descriptions of embodiments thereof that are provided by way of example and are not intended to limit the scope of the invention. The described embodiments comprise different features, not all of which are required in all embodiments of the invention. Some embodiments of the present invention utilize only some of the features or possible combinations of the features. Variations of embodiments of the present invention that are described and embodiments of the present invention comprising different combinations of features noted in the described embodiments will occur to persons of the art. The scope of the invention is limited only by the following claims.

CLAIMS

1. A motion detector for detecting motion of a body in a surveillance zone comprising:

at least one laser that produces laser light;

at least one photodetector that generates signals responsive to light incident thereon;

a light distributor that receives laser light from a laser of the at least one laser and distributes a portion of the light into a plurality of sensor light beams that extend into the surveillance zone and a portion of the light into at least one reference light beam that is incident on a region of the at least one photodetector, wherein the distributor is positioned and configured so that light reflected from a sensor beam by an object in the surveillance zone is received by the distributor and directed onto said region of the at least one photodetector; and

circuitry that receives signals generated by the at least one photodetector and processes the signals to determine if reflected light incident on the at least one detector is Doppler shifted as a result of motion of the body, and if so, generates a signal indicating motion of the body.

2. A motion detector according to claim 1 wherein the at least one reference beam is formed by light that is back distributed by the distributor.

3. A motion detector according to claim 1 or claim 2 wherein the plurality of sensor beams is formed by light that is forward distributed by the distributor.

4. A motion detector according to any of the preceding claims wherein for each sensor beam of the plurality of sensor beams produced by the distributor the distributor produces a mirror image reference beam.

5. A motion detector according to any of claims 1-4 wherein the distributor comprises a surface on which light received from the at least one laser is incident, which surface has a partially reflecting layer that controls how much of the light from the at least one laser is distributed to the at least one reference beam and how much is distributed to the plurality of sensor beams.

6. A motion detector according to any of claims 1-5 wherein the distributor comprises a diffraction grating.

7. A motion detector for detecting motion of a body in a surveillance zone comprising:

at least one laser that produces laser light;

at least one photodetector that generates signals responsive to light incident thereon;

a diffraction grating that receives laser light from the at least one laser and distributes a portion of the light into at least one sensor light beam that extends into the surveillance zone and a portion of the light into at least one reference light beam that is incident on a region of the at least one photodetector, and the light distributor is positioned and configured so that light reflected from a sensor beam by an object in the surveillance zone is received by the light distributor, and distributed onto said region of the at least one photodetector;

circuitry that receives signals generated by the at least one photodetector and processes the signals to determine if reflected light incident on the at least one detector is Doppler shifted as a result of motion of the body, and if so, generates a signal indicating motion of the body;

and wherein the light distributor comprises a diffractor.

8. A motion detector according to any of claims 7 wherein the at least one sensor beam comprises a plurality of sensor beams.

9. A motion detector according to any of claims 1-6, or claim 8 wherein the plurality of sensor beams comprises at least three sensor beams and at least three of the sensor beams are coplanar.

10. A motion detector according to any of claims 1-6, or claim 8 or 9 wherein the plurality of sensor beams comprises at least three sensor beams and at least one of the plurality of sensor beams is not coplanar with at least two of the other sensor beams.

11. A motion detector according to any of claims 1-10 wherein the at least one reference beam comprises a plurality of reference beams.

12. A motion detector according to claim 11 wherein the at least one photodetector comprises a plurality of photodetectors.

13. A motion detector according to claim 12 wherein a different one of the plurality of reference beams is incident on each photodetector.

14. A motion detector according to any of claims 1-10 wherein the at least one photodetector is a single photodetector.

15. A motion detector according to any of claims 1-14 and comprising a motor or actuator that cyclically moves the light distributor back and forth in a given direction so that frequency of light in the at least one reference beam is shifted by a predetermined frequency shift.

16. A motion detector according to any of claims 1-14 comprising an optical frequency shifter through which light reflected from the body passes, which optical frequency shifter generates a predetermined frequency shift in the frequency of the reflected light.

17. A motion detector according to claim 15 or claim 16 wherein the predetermined frequency shift is greater than an expected Doppler shift of the reflected light caused by motion of the body.

18. A motion detector according to claim 17 wherein the circuitry processes signals from the at least one photodetector to determine a frequency difference between the frequency of a reference beam of the at least one reference beam and the frequency of the reflected light and determines that a component of motion of the body that generates the Doppler shift is in a first direction if the frequency difference is greater than the predetermined difference and in a second direction, opposite the first direction, if the frequency difference is less than the predetermined frequency difference.

19. A motion detector according to claim 12 or claim 13 and comprising a first and a second linear polarizer through which light that is incident on a first and a second photodetector respectively of the plurality of photodetectors passes.

20. A motion detector according to claim 19 wherein directions of polarization axes of the first and second polarizers are not parallel.

21. A motion detector according to claim 20 wherein the polarization axes of the first polarizer is substantially orthogonal to the axes of polarization of the second polarizer.

22. A motion detector according to any of claims 19-21 wherein the reference beams that are incident on the first and second photodetectors are generated by the distributor from light from a same laser of the at least one laser, which laser provides linearly polarized light.

23. A motion detector according to claim 22 comprising a polarization detector that detects the direction of polarization of the light from the laser.

24. A motion detector according to claim 22 or claim 23 wherein an angle between the polarization direction of the first linear polarizer and the polarization direction of the laser light is substantially equal to 45^{o}.

25. A motion detector according to any of claims 22-24 and comprising a circular polarizer that circularly polarizes the reflected light.

26. A motion detector according to any of claims 22-24 and comprising a circular polarizer that circularly polarizes light in the reference beams.

27. A motion detector according to claim 25 or claim 26 wherein the first and second photodetectors respectively generate first and second signals responsive to reflected light and reference beam light incident on them, which first and second signals comprise, respectively, first and second signal components having a frequency equal to the Doppler frequency shift of the reflected light caused by motion of the body.

28. A motion detector according to any of claims 1-13 wherein a photodetector of the at least one photodetector is a polarization sensitive photodetector sensitive to light in first and second directions of polarization, which photodetector generates first and second signals that are substantially independent of each other responsive to intensity of light incident on the photodetector having a polarization direction parallel respectively to the first and second directions.

29. A motion detector according to claim 28 and comprising a circular polarizer that circularly polarizes the reflected light.

30. A motion detector according to claim 28 and comprising a circular polarizer that circularly polarizes light in the reference beams.

31. A motion detector according to claim 29 or claim 30 wherein the polarization sensitive photodetector receives light from a single reference beam and reflected light from a sensor beam, both reference and sensor beams being generated by light from a same single laser of the at least one laser, and wherein the first and second signals have first and second signal components characterized by a frequency equal to a Doppler frequency shift of the reflected light caused by motion of the body.

32. A motion detector according to claim 27 or claim 31 wherein the circuitry determines which of the first and second signal components leads the other and if the first signal component leads the second signal component determines a first direction for a component of motion of the body that generates the Doppler shift and if the second signal component leads the first signal component determines a second direction for the component of motion which second direction is opposite the first direction.

33. A motion detector according to any of claims 1-32 wherein the at least one laser comprises a plurality of lasers.

34. A motion detector according to claim 33 wherein at least one of the lasers of the plurality of lasers provides light having a wavelength different from light provided by another laser of the plurality of lasers.

35. A motion detector according to any of claims 1-34 wherein light provided by a laser of the at least one laser is IR light.

36. A motion detector according to any of claims 1-35 and comprising at least one source of visible light, wherein when the at least one source is turned on, light from the source illuminates at least one region of the surveillance zone that is illuminated by light from a sensor beam of the at least one sensor beam.

37. A motion detector according to any of claims 1-36 wherein the at least one reference beam does not extend into the surveillance zone.

38. An intruder detection system for detecting presence of an intruder in a surveillance zone comprising a motion detector according to any of claims 1-37 wherein if the motion detector senses motion of a body in the surveillance zone, the circuitry determines if the Doppler shift is characteristic of motion of an intruder, and if it does generates a signal indicating presence of an intruder in the surveillance zone.

39. Apparatus for guarding an object against theft or damage comprising a motion detector according to any of claims 1-37 wherein at least one sensor beam of the motion detector is incident on the object and, if the object exhibits aberrant motion, generates an alarm.

40. Apparatus for monitoring health status of a person comprising a motion detector according to any of claims 1-37 wherein at least one sensor beam of the motion detector is incident on the person and, if the person exhibits aberrant motion, generates an alarm.

41. Apparatus according to claim 40 wherein the person is a baby and wherein a sensor beam of the motion detector is incident on the baby so as to detect breathing motions of the baby and if the breathing motions exhibit aberrance generates an alarm.

42. A method of detecting motion of an object in a surveillance zone comprising:

diffracting light from a laser of at least one laser to generate at least one sensor beam of laser light that illuminates the surveillance zone;

receiving light from a sensor beam of the at least one sensor beam that is reflected by the object; and

determining whether the received light is Doppler shifted by a frequency generated by a component of motion of the object.

43. A method of detecting motion of an object in a surveillance zone comprising:

generating a plurality of sensor beams of laser light from light provided by a laser that illuminate the surveillance zone;

receiving light from a beam of the plurality of beams that is reflected by the object; and determining whether the reflected light is Doppler shifted by a component of motion of the object.

44. A method according to claim 43 wherein generating a plurality of sensor beams comprises diffracting light from the laser.

45. A method according to any of claims 42-44 wherein determining a Doppler shift comprises generating at least one reference light beam from light provided by the laser and determining whether the reflected light is Doppler shifted with respect to the light in a reference beam of the at least one reference beam.

46. A method according to claim 45 wherein generating at least one reference beam comprises diffracting light from the laser.

47. A method according to claim 45 or claim 46 wherein the at least one reference beam comprises a plurality of reference beams.

48. A method of detecting motion of an object in a surveillance zone comprising:

generating at least one sensor beam of laser light from light provided by a laser that illuminates the surveillance zone;

generating a plurality of reference beams of light from a portion of the light provided by the laser ;

receiving light from a sensor beam of the at least one sensor beam, which is generated from light from the laser, that is reflected by the object; and

determining whether the reflected light is Doppler shifted with respect to light in each of the reference beams by a component of motion of the object.

49. A method according to any of claims 42-48 wherein determining a Doppler shift comprises:

coherently mixing the reflected light with light from at least one reference beam to generate at least one mixed signal; and

determining whether the at least one mixed signal comprises a signal component having a frequency equal to a Doppler frequency shift characteristic of a component of motion of the object.

50. A method according to any of claims 42-49 and comprising introducing a predetermined offset frequency shift in the received light that is larger than an expected

Doppler shift generated by a component of motion of the object, so that the received light has a difference in frequency with respect to the reference beam light that is equal to the sum of the offset frequency shift and the Doppler shift generated by the component of motion of the object.

51. A method according to any of claims 42-49 and comprising introducing a predetermined offset frequency shift in reference beam light that is larger than an expected Doppler shift generated by a component of motion of the object, so that a difference in frequency between the received light and the reference light is equal to the sum of the offset frequency shift and the Doppler shift generated by the component of motion of the object.

52. A method according to claim 50 or claim 51 comprising determining a direction of the component of motion of the object that generates the Doppler shift responsive to whether the magnitude of the difference in frequency between the received light and the reference light is greater than or less than the offset frequency shift.

53. A method according to claim 47 or claim 48 wherein light provided by the laser is linearly polarized and comprising circularly polarizing at least a portion of the reflected light.

54. A method according to claim 53 and comprising linearly polarizing light in a first and second reference beam of the plurality of reference beams in first and second directions respectively.

55. A method according to claim 54 and comprising linearly polarizing first and second portions of the circularly polarized reflected light in the first and second directions and coherently mixing the first and second portions of the reflected light with light in the first and second reference beams respectively so as to generate first and second mixed signals.

56. A method according to claim 47 or claim 48 wherein light provided by the laser is linearly polarized and comprising circularly polarizing light in a first and a second reference beam of the plurality of reference beams.

57. A method according to claim 56 and comprising linearly polarizing first and second portions of the reflected light in first and second directions respectively.

58. A method according to claim 57 and comprising linearly polarizing the circularly polarized light in the first and second reference beams in the first and second directions respectively and coherently mixing the linearly polarized reference beam light with the first and second portions of the reflected light respectively so as to generate first and second mixed signals.

59. A method according to claim 55 or claim 58 and comprising determining first and second signal components respectively of the first and second mixed signals that have a frequency equal to the Doppler shift of the received light.

60. A method according to claim 59 comprising determining a direction of the component of motion of the object that generates the Doppler shift responsive to which of the first and second signal components leads the other.

61. A method according to any of claims 42-49 wherein the laser provides linearly polarized light and comprising:

circularly polarizing light from the laser or the reflected light;

mixing the circularly polarized laser or reflected light with, respectively, the reflected or laser light that has not been circularly polarized;

generating first and second mixed signals responsive to mixed light in first and second polarization directions respectively;

determining first and second signal components respectively of the first and second mixed signals that have a frequency equal to the Doppler shift of the received light; and

determining a direction of the component of motion of the object that generates the Doppler shift responsive to which of the first and second signal components leads the other.

62. A method according to any of claims 53-61 and comprising detecting the direction of polarization of the linearly polarized light provided by the laser.

63. A method for determining presence of an intruder in a surveillance zone comprising detecting motion of the intruder according to any of claims 42-62.

64. A method for monitoring status of an object in a surveillance zone comprising detecting motion of the object according to any of claims 42-62 and if the object exhibits aberrant motion generating a signal indicating the occurrence of the aberrant motion.

65. A method for monitoring health and status of a person in a surveillance zone comprising detecting motion of the person according to any of claims 42-62 and, if the person exhibits aberrant motion, generating a signal indicating the occurrence of the aberrant motion.

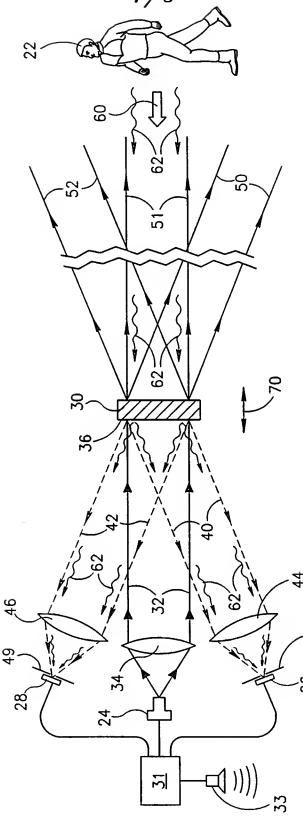
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FIG.1

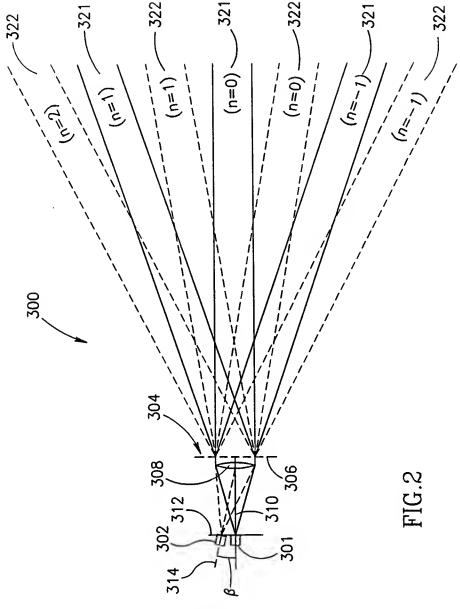
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FIG.2

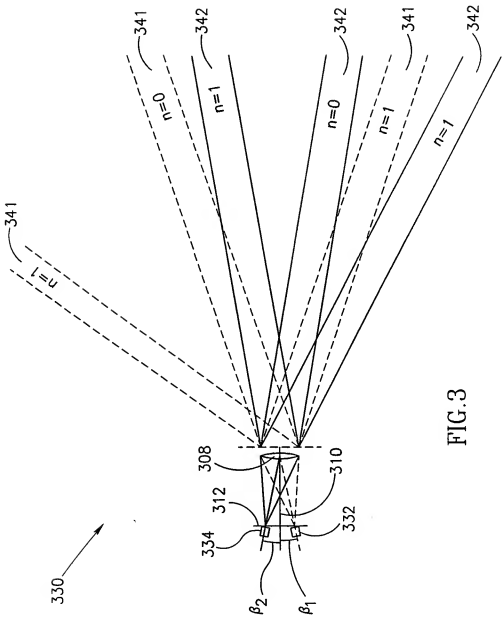
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FIG.3

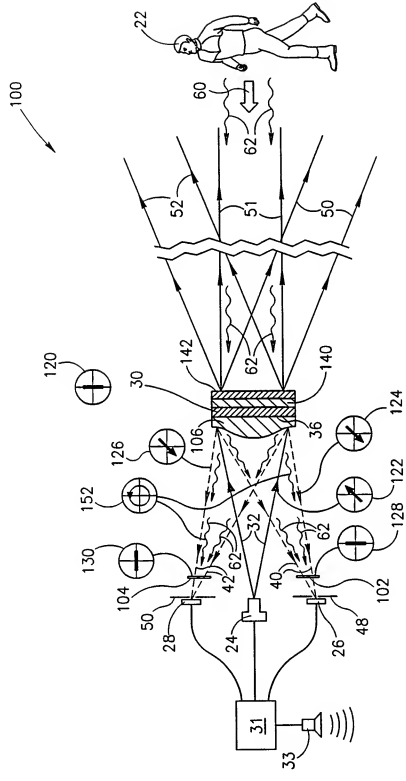
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FIG.4A

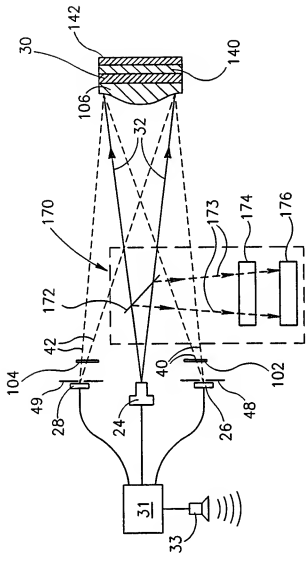
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FIG.4B

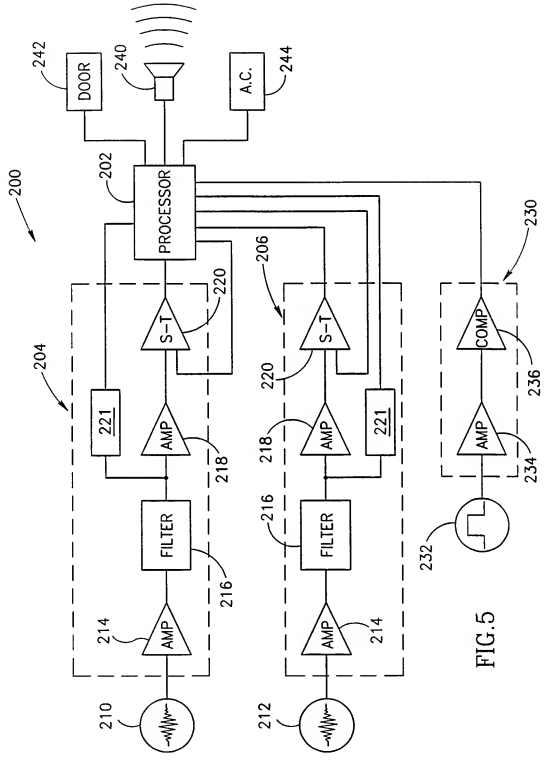
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FIG.5

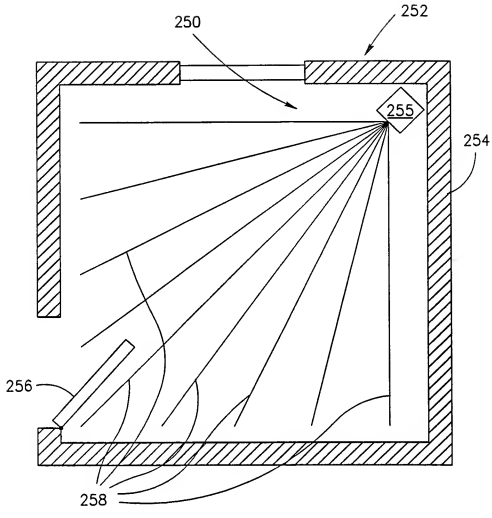

FIG.6

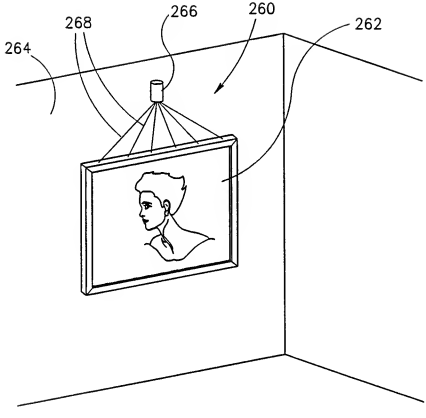

FIG.7
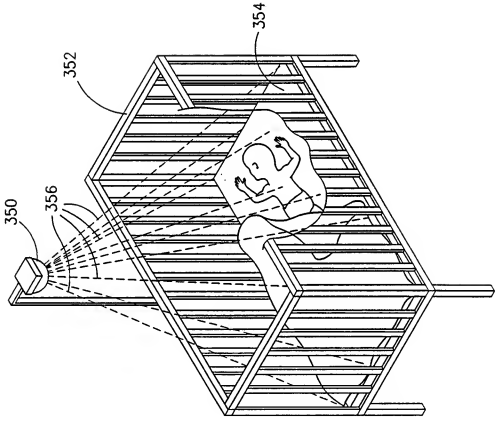
FIG.8